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A DEVICE FOR STAMINA MEASUREMENT OF FINGERLING SALMONIDS

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RESEARCH REPORT 67

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Allan E. Thomas, Roger E. Burrows,

and Harry H. Chenoweth

RESEARCH REPORT 67

UNITED STATES DEPARTMENT OF THE INTERIOR

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FISH AND WILDLIFE SERVICE

Clarence F. Pautzke, *Commissioner*

BUREAU OF SPORT FISHERIES AND WILDLIFE

John S. Gottschalk, *Director*

Published by the Bureau of Sport Fisheries and Wildlife • Washington • 1964

Printed at the U.S. Government Printing Office, Washington, D.C.

CONTENTS

	Page
Introduction	1
Experimental apparatus	2
Testing procedure	3
Performance index	6
Variables in testing	6
Size of fish	6
Water temperature	6
Oxygen content	7
Sampling technique	8
Number of fish	8
Effect of feeding	9
Effect of retesting	9
Species of fish	9
Development of a method of performance rating	10
Factors measured by the tunnel	13
Discussion of evaluation methods	13
Summary	14
Literature cited	14

ABSTRACT

A stamina tunnel was developed to measure differences in physical performance of salmonid fingerlings. By subjecting fish samples to controlled patterns of water velocity, it has proved possible to demonstrate differences in fish stamina imparted by disease, nutrition, and environment.

A DEVICE FOR STAMINA MEASUREMENT OF FINGERLING SALMONIDS

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One of the principal problems of artificial propagation is evaluation of the quality of the fish produced. The physical stamina of the fingerling is assumed to be one measure of the ability of the fish to survive after release. A device for the measurement of physical stamina must meet certain requirements to be of practical value in any large-scale evaluation of hatchery production:

1. The device should be capable of rapidly testing representative samples of hatchery populations.
2. It should be able to reproduce exactly a measured stress.
3. It should be capable of imposing increased stress to conform with increased ability.
4. It should have sufficient sensitivity to measure the stamina differences created by the varying conditions encountered in artificial propagation.

Several methods have been employed to measure the swimming ability of fish. The most popular type of apparatus seems to be a rotating annular trough or "fish wheel." Adaptations of this idea have been used by Bainbridge and Brown (1958), Paulik and DeLacy (1957), Gray (1957), Brett et al. (1958), and others. One fish at a time is tested. The velocity of the water in the trough is essentially that of the trough, although is some designs slippage may occur. The introduction of cages, electrodes, and similar devices for stimulation of the fish increases the slippage between water and trough. If larger samples of fish are to be tested simultaneously, the trough must be wide. The radius must be large if the difference between the inner and outer velocities is to be negligible. The annular trough may also produce a laminar flow of water which may have a different effect on the swimming ability of the fish than would more turbulent water.

Open, straight troughs, such as used by Reimers (1956) and Vincent (1960), and the flume used by Kerr (1953) have the disadvantage of a substantial difference in water velocities within the trough. If the bottom is rectangular, the velocity in the lower corners will be low. Without closely controlled water velocities, fish tested will not all be subjected to the same swimming requirements.

The method of frightening fish for a fixed time interval to produce exercise, as used by Miller et al. (1959) and Hochachka (1961) may result in nonuniform treatment of fish samples. "Closed-circuit" water tunnels such as are described by Mar (1959), Katz et al. (1959), and Davis et al. (1963) have the advantages of closely controlled water velocities and more nearly uniform treat-

The authors wish to receive equal credit for this publication.

ment of fish samples. Under most conditions only a few fish can be tested at one time.

None of the devices described in the literature meets the requirements for large scale evaluation of stamina in hatchery fish. Our stamina tunnel was designed to meet these requirements. It has been tested over a period of 4 years with thousands of fish samples from different sources and has proved adequate for stamina measurement. By recognition and control of extraneous variables it has been possible to measure fish performance differences imparted by disease, nutrition, and environment.

EXPERIMENTAL APPARATUS

The stamina tunnel was designed specifically for stamina measurement. In these measurements the search is for differences imparted by artificial propagation and not precise determinations of swimming speeds. The tunnel is comparatively large in order to test large samples. Control of water velocities is exact and reproducible with but minor error. The velocities available are in excess of the requirements for testing small fingerlings and thereby provide reserve velocities for the imposition of additional stress. Design drawings of the tunnel are shown in figure 1. In this tunnel the water is

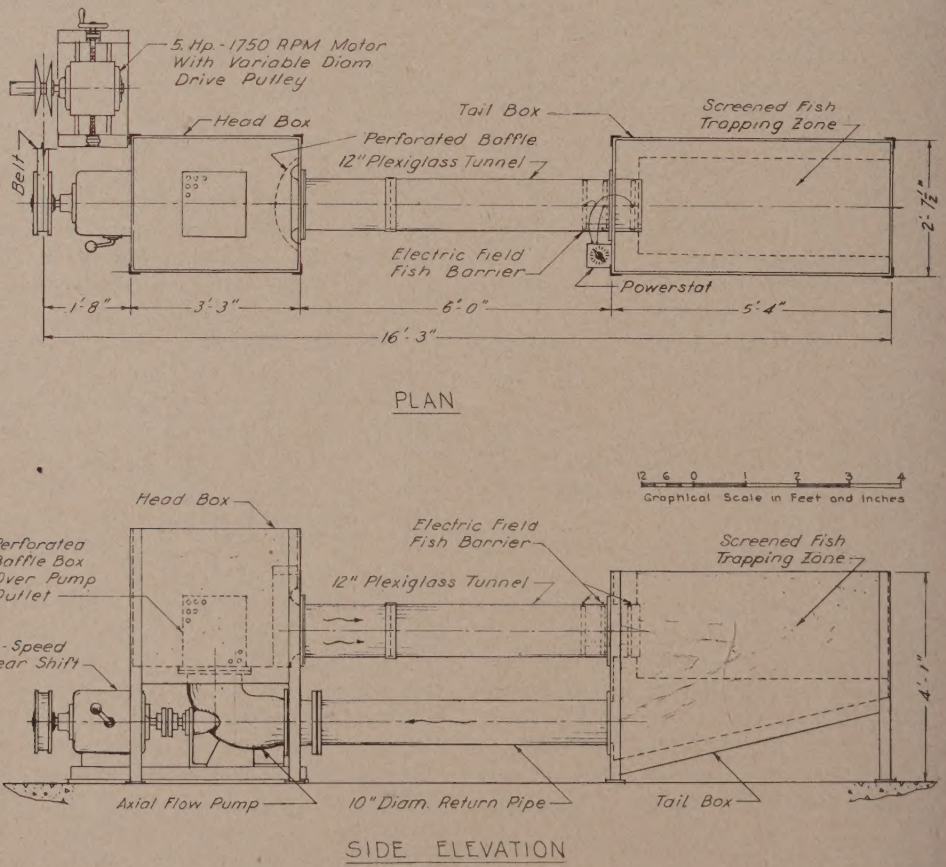

FIGURE 1.—Design drawings of the stamina tunnel.

recirculated by means of a 1,500 gallon per minute axial flow pump. A four-speed transmission and variable-speed drive pulley are combined to allow a wide range of water velocities to be produced. Speeds can be varied within each of the four ranges while the pump is running.

The discharge from the pump passes through perforated baffles upon entering the head box. These baffles are designed to provide adequate diffusion at both high and low velocities. The holes of the baffles are small so that the resulting turbulence will be fine and therefore will dissipate quickly. The size of the holes in these baffles will depend on the water velocities desired for the tunnel.

The head box is adequate but is near the minimum size necessary to meet the capacity of the pump. Two perforated plates are located at the entrance to the tube, the first to produce a more uniform flow and the second to confine the fish.

The tunnel consists of a 12-inch outside diameter plexiglass tube, 6 feet in length. The flow through the tunnel is controlled by a differential in water level between the head and tail boxes. The fixed cross-section of the 12-inch tube makes the velocities through the tube a direct function of the mass flow rate of the pump. For a fixed water path this flow is a function of pump speed. The rotational rate of the pump can easily be varied and measured.

A uniform velocity at the entrance of the tunnel is secured by the well-rounded bell mouth. A considerable fluid acceleration takes place at the tunnel entrance. It is this acceleration which creates the uniform velocity. The round cross-section helps to maintain this uniform velocity although any boundary will retard the motion of the adjacent flow. The final velocity profile is obtained 50 pipe diameters downstream from a well-rounded intake in a long pipe. Since this water tunnel has a length of only 6 pipe diameters (6 feet), the velocity profile in the tunnel is changed only slightly throughout its length. Typical velocity profiles obtained at the tunnel outlet are shown in figure 2. The velocity in the upstream test section will be even more uniform because the boundary layer has had less opportunity to slow down the flow near the wall.

An electrical field fish barrier is located near the outlet of the tunnel. Three stationary aluminum bands are positioned inside the tunnel. Electrical fields are created between the positive middle band and negative bands on either side, and the strength of the fields is controlled by a variable transformer.

Fish leaving the tunnel during a stamina test are held in a screened trapping zone or collection chamber of the tail box. The water diffuses through the screens to the tail box sump, from which it enters the return pipe to the pump.

Energy is added to the fluid on each pass through the pump. This energy eventually is converted to heat. The computed rise in the water temperature with a tunnel velocity of 2 feet per second was under 0.5° F. per hour of continuous operation. This insignificant rise is masked by heat transference from the air and is corrected between stamina tests by the addition of more water at 53° F. temperature.

The design of the tunnel has proved very satisfactory for stamina testing of fingerling salmon. No alterations in design have been found desirable.

TESTING PROCEDURE

In the normal procedure of stamina testing, the fish are segregated into groups, temperature acclimated, tested in the tunnel, and weighed after testing. Samples from the lot to be tested are randomly distributed into groups of 100 fish each. These samples are held sepa-

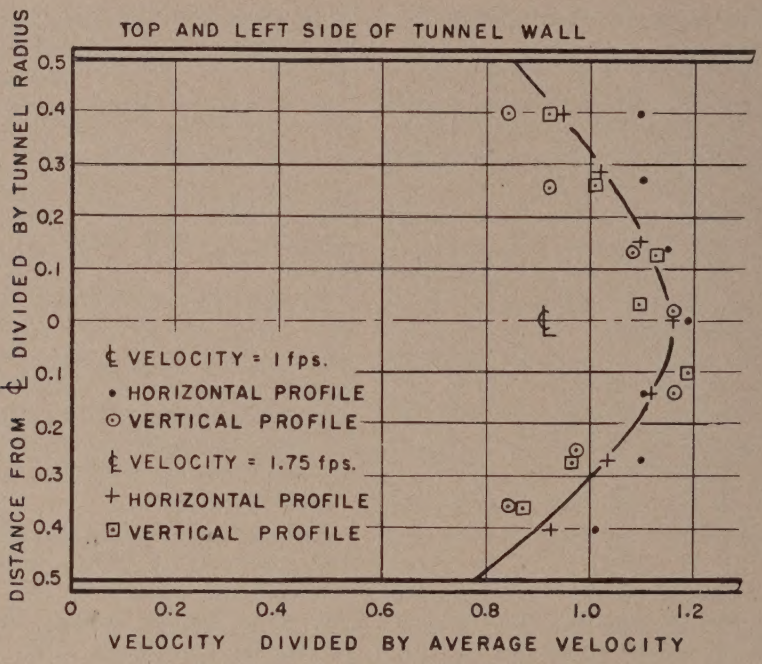

FIGURE 2.—Velocity profiles at tunnel outlet.

rate and acclimated to 53° F. water for a period of 16 to 20 hours. The fish are not fed during this time. At the end of the temperature acclimation period, the group of fish is introduced into the clear-plastic tunnel by means of a removable loading chute. After a brief orientation period, a procedure of increasing the water velocity by increments is begun.

The size of the tunnel is such that a standard sample of even large fingerlings is not crowded. The distribution of fish in the tunnel is shown in figure 3. Under test conditions, the tunnel is covered during operation to reduce the possibility of outside disturbance and to allow the fish to orientate within the tunnel.

The electrical field at the outlet induces the fish to remain in the tunnel until partially exhausted. When they can no longer maintain their position against the water current, the individual fish are swept through the electrical field into the tail box where they are held until the end of the test. The voltage used in the electrical field varies from 7 to 12 volts with the setting depending upon the size of fish tested. The lower voltage is used for the larger fingerlings.

The water velocities and exposure times under two operating procedures of stamina testing are shown in figure 4. Fish ranging from approximately 1 to 4.5 grams per fish are normally tested in second gear at water velocities ranging from 0.45 foot per second to 1.70 feet per second. Larger fingerlings are usually tested in third gear with water velocities from 0.75 foot per second to 2.70 feet per second. Smaller fish are given an advantage of less initial velocity, which is not necessary for larger fish. The testing procedure gives two identical velocity

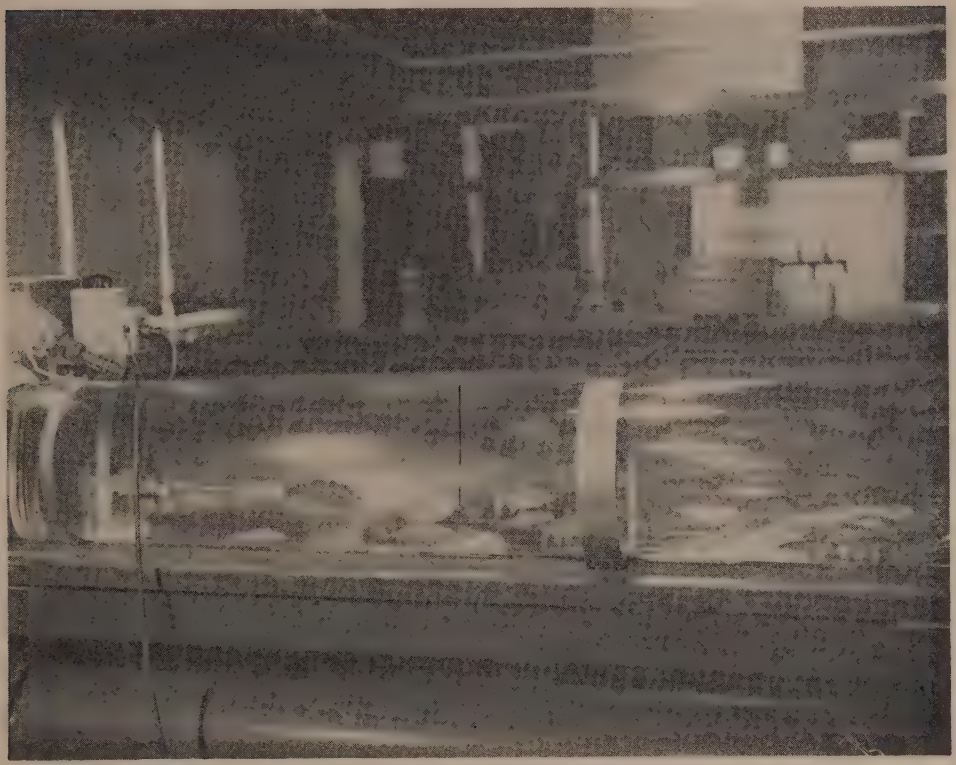

FIGURE 3.—Closeup showing the normal distribution of fish in the plexiglass tunnel at a low water velocity.

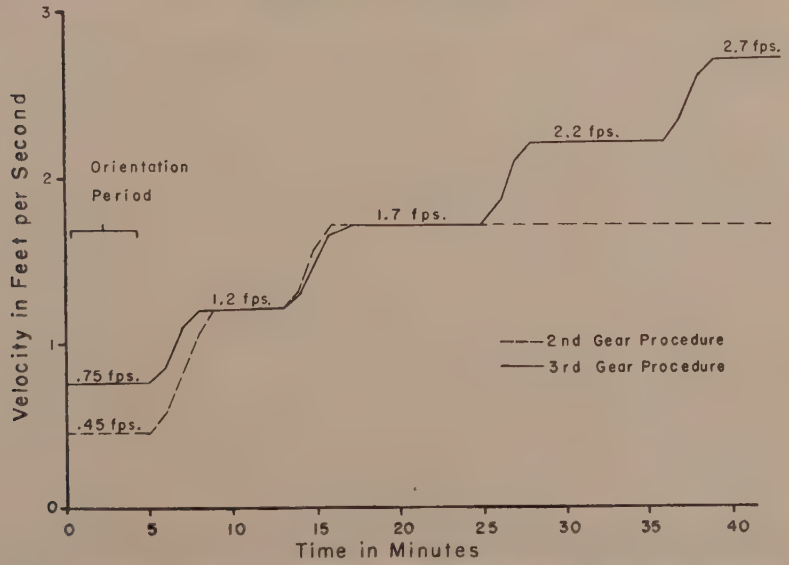

FIGURE 4.—Water velocities and exposure times for stamina testing using two gear speeds.

plateaus of 1.2 feet per second and 1.7 feet per second for both gears, and two additional plateaus of 2.2 feet per second and 2.7 feet per second for the third gear.

The fish are counted as they leave the tunnel, and the cumulative totals are recorded at 1-minute intervals. The stamina test is completed when at least 75 percent of the fish have left the tunnel. At the conclusion of each test the total weight of each sample is determined.

PERFORMANCE INDEX

A performance index has been developed for the stamina measurement of comparable fish samples. This index is the summation of the times when 25 percent and 75 percent of the fish leave the tunnel. The index measures the swimming ability of only the middle 50 percent of the fish tested and eliminates the strongest and weakest fish. The elimination of these fish keeps to a minimum any possible effect due to the abnormal performance of a few fish.

The performance index has proved valuable in a great number of stamina tests as a rapid and reliable method of measurement. Fish size, however, affects swimming ability and therefore the performance index. A normal performance curve can be established for a population of fish by conducting a series of tests during different periods of their growth. The existence of differences between fish populations can then be determined by comparing the performance indexes with the established values for fish of the same size. In past testing, a difference in the performance index of about three points between fish of the same size has usually been a significant difference.

VARIABLES IN TESTING

There are a number of controllable variables which must be considered if testing is to be standardized. These controllable variables are size of fish, water temperature, oxygen content, sampling technique, size of sample, starvation period, frequency of retesting, and species of fish.

Size of fish

Under normal conditions the performance of fish improves with an increase in size. Kerr (1953) in testing the effects of water velocity on juvenile striped bass (*Roccus saxatilis*) and chinook salmon (*Oncorhynchus tshawytscha*) found an increase in swimming ability with larger fish and little difference between the ability of comparable yearling salmon and bass. Bainbridge (1960) found an increase in the swimming speed of goldfish (*Carassius auratus*), dace (*Leuciscus leuciscus*), and trout (*Salmo irideus*) with an increase in fish length.

That the swimming ability of fish increases with an increase in size is demonstrated in figure 5. The data for this graph were obtained from a series of stamina tests on fall chinook salmon fingerlings conducted at biweekly intervals during a rearing season. Five hundred fish were tested at each interval, and a total of 9,000 fish were used to determine the normal performance curve.

Water temperature

The swimming ability of fish has been found to be affected by the temperature of the water. Brett et al. (1958) found that young coho salmon (*O. kisutch*) increased their cruising speed with increases in temperature up to their ultimate lethal temperature, whereas the cruising speed of young sockeye salmon (*O. nerka*) reduced when the lethal temperature was approached. Fry (1958) reports that the cruising speed of young goldfish reaches a peak and then decreases when higher temperatures cause a stress that increases the standard metabolic rate.

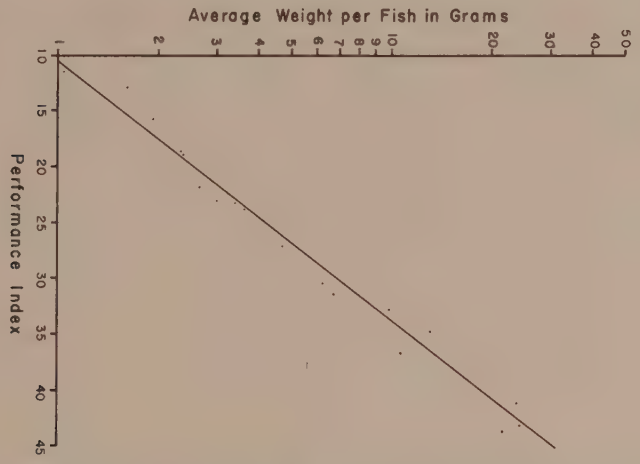

FIGURE 5.—Increase in swimming ability with increase in weight in fingerling fall chinook (*O. tshawytscha*).

The effects of the water temperature on metabolic rate of the fish are complex. Brett (1956) states that fish performance is best in the region of the "preferred temperature" and that temperatures above and below that range produce adverse results. Brett (1959) reports that sockeye salmon increase their swimming speed with increased water temperature until about 60° F. is reached. Above this temperature, he found, swimming speed is reduced until the speeds at 50° F. and 66° F. are approximately equal. The increased metabolic demand at the elevated level, however, would cause the energy reserves to be exhausted 1.5 to 2 times as fast at 66° F. as at 50° F.

To eliminate the temperature effect, stamina tests are normally conducted with acclimated fish at a constant water temperature of 53° F. This temperature gives a common base from which to compare populations of fish with different dietary and environmental regimens as well as with wild and hatchery fish from other geographical areas.

Temperature experiments in the stamina tunnel indicate that the temperature of water at time of testing has a definite effect on the swimming ability of the fish. During 1960, tests on summer chinook fingerlings were conducted at water temperatures ranging from 47.5° F. to 60° F. Fall chinook fingerlings have been tested at temperatures from 38° F. to 54.5° F. Within these limits, better performance in the stamina tunnel has resulted from increased water temperature.

In addition to the temperature effect on fish physiology, there is a change in physical resistance due to changes in water viscosity. The effect of temperature on the viscosity of the water is shown in figure 6. Both the physical and physiological conditions created by cold water temperatures result in reduced performance, and these factors must be recognized in performance evaluations.

Oxygen content

In studies by Davis et al. (1963) and Katz et al. (1959), reductions in oxygen concentration resulted in corresponding reductions of the maximum sustained swimming speeds of coho and chinook juvenile salmon. In the stamina tests, fish performed in water at 90 percent of ox-

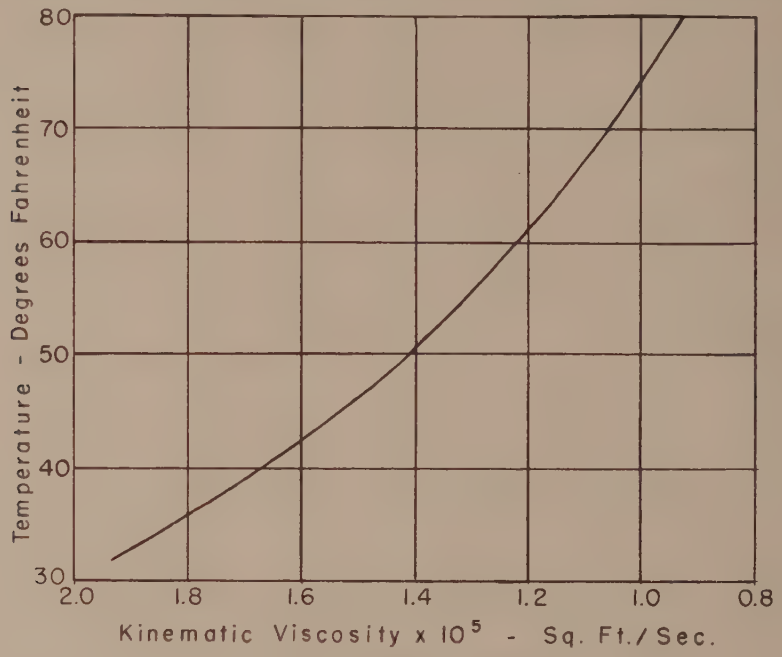

FIGURE 6.—Viscosity of water.

ygen saturation. Replenishment of water between tests assured standard conditions without the depressing effect of an oxygen deficiency.

Sampling technique

The biological variation among fish from the same diet or rearing environment is such that random samples of the fish population are necessary to give reliable data. The entire population must be handled and systematically sampled with a vertical sampler. The variables to be encountered in methods of sampling are described by Hewitt and Burrows (1948). Dip net samples may be necessary to test the progress of long-term experiments, but the results will be biased. Under such circumstances the samples should be taken either during feeding when the fish are congregated in a small area or when the fish are seined into a small section of a pond. These procedures do not permit the selection of true samples but are the best possible compromise.

Number of fish

Samples varying from 13 to 264 fish have been tested in the tunnel, with a trend towards better performance in the smaller samples. Samples of the same numbers from one population of fish perform similarly. Fish are tested in 100-fish groups to reduce the bias from biological variation which might result from fewer fish and to facilitate the evaluation of results. Standardization of the sample size rather than the actual number of fish employed appears to be the important factor in comparing populations. From two to five stamina tests of 100 fish each are normally conducted for each population to allow statistical analysis of the results.

During early testing of fish with the stamina tunnel, the question arose whether the first fish out of the tunnel were actually the weakest fish, and the last ones the strongest, or were they simply crowding each other out. In several groups of fish, the first and last 25 percent of the fish coming out of the tunnel were separated during the test and the quarters were individually retested. The quarters closely repeated their original levels, disproving any crowding effect.

Effect of feeding

As mentioned earlier, samples of fish to be tested are usually not fed for at least 16 to 20 hours before being tested. Fish which are tested within a few hours after being fed perform poorly in the tunnel.

Tests on the effects of starvation on performances, using fall chinook fingerlings averaging 1 gram per fish, resulted in no decrease in swimming ability until after 5 days without food. Fall chinook fingerlings averaging about 3 grams per fish had no performance decrease for at least 4 days of starvation. Tests on summer chinook fingerlings averaging about 15 grams per fish showed no difference in performance for at least 40 hours without food.

It would appear that, once the initial digestive period is past, the energy requirement for normal swimming can be met for a period of several days. In any study combining stamina testing with other evaluations of a population which might be influenced by starvation, a fixed time interval between testing and feeding should be established.

Effect of retesting

In some instances, such as a series of tests conducted on a small population of fish, it might be necessary to run stamina tests on fish of which all or part had previously been tested. Preliminary experiments on retesting, using summer chinook fingerlings, showed a substantial decrease in performance when immediately retested. Retesting of the fish after a rest of 24 hours produced a significant reduction in swimming ability below the initial level. In tests with fall chinook fingerlings, paired groups of 100 fish each were retested after resting periods of 1, 2, and 3 days. After 3 days of rest, the performance had returned to the previous level.

Species of fish

Most stamina tests have been conducted with hatchery-reared fall chinook salmon. Summer chinook and rainbow trout (*S. gairdneri*) fingerlings as well as spring chinook and steelhead yearlings have also been tested from hatchery stock. Tests have been conducted on spring chinook, steelhead, and coho salmon yearlings from rearing ponds. Wild fish tested in the tunnel include both fingerling and yearling fall chinook and coho salmon as well as spring and summer chinook and steelhead fingerlings.

Stamina tunnel tests indicate that fall chinook fingerlings, generally, have a higher performance level than spring and summer chinook fingerlings of the same size. This may indicate an inherent difference between the races. Collins (1958) measured the performance of adult chinook salmon in fishways and found that fall chinook were faster and more consistent swimmers than springs.

In a few tests of wild spring chinook from the Entiat River in Washington, fewer fish came out of the tunnel during the early part of the stamina test than in tests of hatchery samples of the same weight; hatchery fish of the same age but slightly larger showed the same or better performance levels. Samples of wild fall chinook gave considerably lower results than hatchery fish; these wild fish had

come from an eddy area of the Cowlitz River in Washington and were probably not typical specimens. Coho salmon fingerlings were found to have slightly less swimming ability than fall chinook. Steelhead fingerlings were able to outperform comparable fall chinook. Wild coho salmon yearlings gave a poor performance owing to malnutrition, but had a 50-percent increase after being fed for 3 weeks in the hatchery, and doubled their original performance after 6 weeks of feeding.

Studies by Paulik and DeLacy (1957) on adult steelhead and coho salmon from the same stream and under identical conditions demonstrated that steelhead could outperform coho at high water velocities. Performance of sockeye salmon (Paulik and DeLacy, 1958) reduced as the distance from the ocean increased. These studies show that there are hereditary differences in the swimming ability between species of fish which persists into the adult form.

A question may arise as to the validity of comparing the performance of fish at different stages of their behavioral development, that is, comparing fish which are migrating downstream with those at earlier stages. Young steelhead, spring chinook, and coho salmon, when trapped by downstream migrant traps and later tested in the stamina tunnel, lost their tendency to migrate and swam against the current in the typical manner. This regression to an earlier stage is explained by Hoar (1958). His work on fish behavior has shown that a change in the natural sequence of stimuli, such as a barrier to migration, may cause "fall-back phenomena" to an earlier stage.

DEVELOPMENT OF A METHOD OF PERFORMANCE RATING

A method of evaluation was sought which would compensate for some of the uncontrollable variables encountered in stamina testing and thereby enable the assignment of a relative standing for performance comparison. The work done or energy expended by the fish in overcoming fluid resistance in the tunnel was selected as the logical method of performance measurement. In its simplest form, the work done is expressed in terms of force and distance. The drag forces encountered, the varying velocities imposed during the stamina trials, and the length of time the fish are capable of maintaining themselves in the tunnel, all are factors affecting the energy expended. These factors may be measured in the tunnel, or the effects may be calculated from accepted hydraulic formulas.

The drag force on an immersed body is usually expressed as $D = C_d A P V^2$ where C_d is a coefficient that depends upon the shape of the body and upon Reynolds number, A is the frontal area of the body, P is the mass density of the fluid, and V is the relative velocity between the body and the fluid. Reynolds number is a similarity criterion indicating the relative importance of inertial and viscous forces on the flow pattern. For fish, Reynolds number would logically be $N_r = VL/v$ where L is the length of the fish and v is the kinematic viscosity of the water at the existing temperature (fig. 6).

For fish of the same general shape, equal Reynolds numbers would indicate similar flow patterns about the fish. Kinematic similarity is said to exist about two immersed bodies if the ratio of velocities at all corresponding points is constant. If the local water velocity past a fish is 1½ times the speed of a small fish, it is also 1½ times the speed of a large fish if the Reynolds numbers are equal and geometric similitude exists.

The drag on an immersed body arises from two sources, shearing stress and normal stress. The first of these is called frictional or surface resistance, and the

second is called form drag. Frictional drag on fish can be represented in a manner similar to that of a flat plate pushed through a fluid with the plate parallel to the direction of motion. Gray (1957) suggests that this is a reasonable assumption. Form drag can be reduced by streamlining or by devices that control boundary layer growth on the immersed body. A fish is highly streamlined, and his drag is essentially due to frictional or surface effects.

For values of Reynolds number below about 400,000, the coefficient of drag may be expressed as $C_d = \frac{0.7}{\sqrt{N_r}}$. Fish within a species have geometrically similar bodies, and the surface area varies with the square of the length of the body. Substituting these expressions into the drag equation yields $D = C_1 L^{3/2} P V^{3/2} \nu^{1/2}$ where C_1 is a proportionality constant whose numerical value could be determined. The effects of water temperature and fish size on the resistance to motion and the energy expenditure required in overcoming this resistance can now be deduced.

An example of resistance would be fish moving through water at 35° F. and then through water at 82° F. The fluid is approximately twice as viscous at 35° F. as at 82° F. At the lower temperature, the fish would find it much more difficult to attain high speed. Reference to the last equation shows that for the same speed the water resistance to motion would be 41 percent greater at 35° F. than at 82° F.

The next consideration is the effect of size on resistance and power. A 10-centimeter and a 20-centimeter fish can be used for illustrative purposes. If swimming in the same water at the same speed, the drag equation indicates that the resistance to motion of the larger fish will be 2.83 times that of the smaller fish, the power required will also be 2.83 times that of the smaller fish. This additional resistance should not tax the larger fish. His volume and weight are about eight times that of the shorter fish and he should have the musculature and energy necessary to reach a correspondingly greater speed.

If output power is proportional to weight, the 20-centimeter fish should swim at about 1.5 times the speed of the 10-centimeter fish. Substitution of these lengths and velocities into the drag equation will show that resistance to motion under this latter condition is 5.3 times as great for the larger fish as for the smaller fish. The work required is the product of resistance and velocity and is eight times as great for the larger fish as for the smaller one.

The work performed by a swimming fish moving with variable speed through a series of increments with constant velocity during each increment is expressed as follows: Work $= \Sigma (D_1 S_1 + D_2 S_2 + D_3 S_3 \ldots.) = \Sigma D_i S_i$. Here D_i is the drag force during the increment and S_i is the distance swum during the increment. Since the distance traveled by the fish during the increment of contant velocity is equal to the velocity multiplied by the length of the time interval T_i, Work $= \Sigma D_i V_i T_i$.

The equation for drag force was earlier written as $D = C_2 L^{3/2} P V^{3/2} \nu^{1/2}$. For water near 54°F. the viscosity can be approximated by the formula $\nu = 54/\text{F.}^\circ (1.3 \times 10^{-5})$. Making this substitution into the drag equation gives $D = C_2 L^{3/2} P V^{3/2} (54/\text{F.}^\circ)^{1/2}$. The work equation can now be written: Work $= C_2 L^{3/2} P (54/\text{F.}^\circ)^{1/2} \Sigma V_i^{5/2} T_i$.

All the variables on the right side of the above equation can be evaluated by measurements. The method of operating the stamina tunnel allows for the determination of $\Sigma V_i^{5/2} T_i$. The effect of fish size and water viscosity can be calculated.

The muscle power of the fish must be based on a set of assumptions. A common and reasonable assumption is that the swimming ability of a fish should be proportional to his muscle weight. Gray (1957) goes so far as to estimate the constant of proportionality as 0.002 horsepower per pound of body weight. Two other assumptions to be made are: (1) muscle weight is some fixed fraction of the body weight, and (2) fish weight varies as the cube of the fish's length. The last assumption has been investigated by Le Cren (1951), who found the exponent to be between 2.5 and 4.0 for perch, and by Bainbridge (1960), who found the exponent to be 3.2 for goldfish, 3.0 for trout, and 2.8 for dace. Based on the three stated assumptions, the ratio of useful work done to the muscle power available for this purpose may be expressed in the equation: Performance

$$\text{rating} = C_3 \sqrt{\frac{54}{\text{F.}} \times \frac{1}{\text{Wt.}}} \; \Sigma V_i^{5/2} T_i.$$

Since only relative performance is meaningful, the constant C_3 can be arbitrary as long as it is applied to all samples. A constant of 174 has been used with fish tested in the stamina tunnel as it places the expected performance of chinook salmon fingerlings reared in raceway ponds at 100.

The portions of the sample selected for evaluation in the performance rating differ from those used in the performance index. In energy measurements the energy expenditure varies as the square of the velocity. In the tunnel tests fish are subjected to periodic increases in velocity. As the variation in swimming ability can vary considerably within a sample, it is entirely possible for the excellent performance of a few fish to obscure the poor performance of the majority of the lot. To correct for this possible distortion, the ratings are based on the cumulative energy expenditure of 50 percent and 75 percent of the sample.

A high value for the performance rating does not necessarily mean that a fish has expended a large amount of energy. It does indicate that the fish performed well compared with what would have been expected from him. The rating should not be applied to fish over 50 cm. long because the flow pattern around such fish is not likely to be similar to that used in the derivation of the formula.

Table 1 lists the calculated values for the energy expenditure measurement, $\Sigma V_i^{5/2} T_i$, calculated for the regimen used in the normal testing procedure of the stamina tunnel. If identical water velocities and exposure times are used in other tunnels the table values will be applicable.

Table 1.—Calculated values for $\Sigma V_i^{5/2} T_i$ under normal testing procedure.

Time	$\Sigma V_i^{5/2} T_i$	
	Second-gear procedure	Third-gear procedure
1 minute	0.136	0.488
2 minutes	0.272	0.976
3 minutes	0.408	1.464
4 minutes	0.544	1.952
5 minutes	0.680	2.440
6 minutes	0.930	3.130
7 minutes	1.550	4.340
8 minutes	2.750	5.920
9 minutes	4.330	7.500
10 minutes	5.910	9.080
11 minutes	7.490	10.660
12 minutes	9.070	12.240
13 minutes	10.640	13.810
14 minutes	12.490	15.670
15 minutes	15.020	18.200
16 minutes	18.360	21.540
17 minutes	22.130	25.310
18 minutes	25.900	29.080
19 minutes	29.670	32.850
20 minutes	33.440	36.620
21 minutes	37.210	40.390
22 minutes	40.980	44.160
23 minutes	44.750	47.930
24 minutes	48.520	51.670
25 minutes	52.290	55.470
26 minutes	56.060	60.590
27 minutes		66.840
28 minutes		73.990
29 minutes		81.140
30 minutes		88.290
31 minutes		95.440
32 minutes		102.590
33 minutes		109.740
34 minutes		116.890
35 minutes		124.040
36 minutes		131.190
37 minutes		139.390
38 minutes		149.990
39 minutes		161.990
40 minutes		173.990
41 minutes		185.990
42 minutes		197.990

FACTORS MEASURED BY THE TUNNEL

It has been demonstrated that the stamina tunnel can measure differences in the performance of fish affected by disease, imbalanced diets, or different environments. In the evaluation of fish affected by disease, infections of the gills resulting in extensive proliferation of the epithelial layer or fusion of the lamellae and filaments produce the most obvious reductions in performance. Other infections causing general debilities are readily measurable by inferior performance. Salmon fingerlings with hematocrits below 30 percent perform poorly in the tunnel. Excessively fat fish have a lowered stamina. Rearing ponds which develop sufficient water velocity to exercise the fish produce fingerlings with superior stamina. Fish from overcrowded ponds have reduced ability to perform. All of these differences may be imposed by variations in methods of artificial propagation. If such physiological differences affect the potential of the fingerlings for survival then the measurement of physical stamina by means of the tunnel may prove to be a valid measure of the survival potential of the fingerling at time of release. Experiments are in progress to determine whether stamina as measured by the tunnel is a factor influencing adult survival.

DISCUSSION OF EVALUATION METHODS

The methods of evaluation developed for the stamina tunnel are the performance index and the performance rating. There are advantages and disadvantages in the use of either method.

The performance index is derived from an easily calculated empirical formula and represents the cumulative time that parts of a sample remain in the tunnel. It does not account for the effect of either fish size or water temperature. In the evaluation of fish of different sizes, a standard curve should be established for a population of fish during a rearing season, and the performance indexes of other samples should be compared with that curve. The performance level is also dependent upon the temperature of the water, and the interpretation of results from tests in varying water temperatures would be difficult.

The performance rating is based on the energy expended by the fish and compensates for both the weight of the fish and the viscosity of the water. It expresses the relation of a sample to the normal or expected performance of fish of that size regardless of the water temperature at which the fish were tested.

A performance index above a certain level may be necessary for the survival even of fish with a normal performance rating. A very small fish may have the normal swimming ability for fish of this size but this ability may not be sufficient to allow him to escape predation. Survival studies with chinook salmon at the Spring Creek Hatchery in Washington (Junge and Phinney, 1963) indicate a much greater survival rate for fingerling releases than for releases of fry. Cope and Slater (1957) evaluated spring and fall releases of chinook salmon from the Coleman Hatchery in California and found a higher survival rate in the larger fish released in the fall. Although the numerous factors affecting survival are quite complex, the size of the fish and its swimming ability at the time of release are certainly important. Experiments now in progress will further determine the importance of both size and stamina on the numbers of returning adult salmon.

It is concluded that both methods of evaluation are desirable, the performance index to determine swimming ability and the performance rating to determine the relation of the sample to the expected performance of the animal.

SUMMARY

A stamina tunnel for comparison of physical capabilities of fingerling salmonids has been designed, developed, and evaluated. The design is such that water velocities varying from 0.4 feet per second up to 5.0 feet per second may be produced, increased, and reproduced in practically infinite velocity increments. The velocities are produced by means of an axial flow pump which creates head differentials between the intake and outlet of a 12-inch-diameter, 6-foot-long, plastic tube. The increments are controlled by regulation of the pump speed.

A testing pattern containing several velocity plateaus correlated with fixed exposure times has been developed for the testing of fingerling salmonids varying in weight from 1 to 50 grams.

A performance index has been evolved to assess the stamina of the individual fish samples and a performance rating to evaluate the significance of differences between samples.

The controllable variables affecting performance include fish size, water temperature, oxygen content, sampling technique, sample size, starvation period before testing, and recovery period before retesting. The existence of such variables makes the standardization of testing techniques imperative. Differences in performance exist also between species and races within species of salmon and trout.

By means of the tunnel it has been possible to demonstrate that varying methods of artificial propagation measurably affect the physical stamina of salmonids owing to conditions imposed by disease, nutrition, and environment.

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1964—743-784

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